Demetrios Demetriades
Kenji Inaba
Philip D. Lumb
Editors

Atlas of Critical Care Procedures

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To my parents, my wife Elizabeth, my daughters Alexis and Stefanie,
and my son Nicholas.

Demetrios Demetriades

To Christine

Philip Lumb

To my parents, Susie and Koji, thank you for all of your support.

Kenji Inaba

Foreword

The ICU in the Baltimore City Hospital was organized in the mid-1950s by a young anesthesiologist named Peter Safar. Peter determined that patients cared for in his ICU would benefit from the continuous presence of a seasoned physician alongside a group of expert critical care nurses and other professionals. His invention of the intensivist-led, multiprofessional team secured Peter's place as one of the founding fathers of critical care medicine. Peter would go on to become the second President of the Society of Critical Care Medicine, Professor of Anesthesiology at the University of Pittsburgh, and eventually a personal mentor and dear friend.

I knew none of that history in the fall of 1980 when I found myself assigned to that very ICU. I was a surgical intern—precisely one season past graduation from medical school—looking after a dozen very ill patients, including a man who had undergone repair of a large abdominal aortic aneurysm. In those days, the procedures were all "open"—endovascular repair had not yet been conceived—and the associated blood loss and fluid shifts were routinely managed based on interpretation of data gleaned from a pulmonary artery catheter. Every hour the nurse would "shoot an output and measure the pressures"; the intern would compute the various indices using a calculator bolted to a rolling cart; and decisions would be made about the next hour's fluid management.

Around 2:30 in the morning I was summoned to the bedside. The patient had apparently woken with a start and, in his postoperative delirium, had thrashed violently. While the endotracheal tube remained secure, the pulmonary artery catheter had found its way to the floor. According to the nurse, I turned somewhat pale. I called the chief resident who graciously listened to my tale of woe and subsequently uttered three words before severing the connection: "Put it back."

According to the nurse, I was no longer pale. I was chalk white. I explained that I had never "floated a Swan-Ganz" (period jargon—the PA catheter had been invented by Drs. Swan and Ganz). She looked at me, muttered something about "interns," and cheerfully remarked, "No problem, read the package insert, I'll talk you through it."

I learned several things that night. First, critical care nurses are the best professional partners on earth. They just want to get things done right for the patient. Second, package inserts are next to useless—or at least they were at the time. Third, critical care is a discipline with a constellation of procedures that have to be learned, mastered, and passed on. Finally, I learned that a good atlas of critical care procedures didn't exist, and learning was based on the "see one, do one, teach one" model.

Suffice it to say that we completed the 20-min pulmonary artery catheter insertion in just under an hour. The patient survived. I chose critical care as my specialty. I am still teaching—and learning—the finer points of the dozens of procedures performed at the bedside of critically ill patients around the world. And the world now has a first class atlas of critical care.

I could have made good use of Chap. 14 in this new atlas that fall night in Baltimore almost four decades ago. I am sure that I will make good use of all of the other chapters in this new ***Atlas of Critical Care***. I am sure that you will also make good use of the knowledge and insight contained herein.

Timothy G. Buchman, PhD, MD, FACS, FCCP, MCCM

Preface

It is appropriate that the *Atlas of Critical Care's* editorial home is the Los Angeles County + University of Southern California Medical Center (LAC+USC MC), the professional home of Max Harry (Hal) Weil who is credited as being the father of critical care medicine. In 1958 Weil noted that patients were more likely to die at night and postulated that the sickest among them may benefit from personal and specialized care delivered by specially trained professionals; this led to the creation of a four-bed (shock) unit at the LAC+USC MC and is legitimately recognized as the first unit organized for the specific purpose of specialized care. His interests in circulation and cardiovascular pathophysiology led to major developments that are now standard in the field: the "stat lab," lactate measurement, and the concept of continuous cardiovascular and hemodynamic monitoring via computerized systems. Weil spent the majority of his career at the USC and in later years was joined there by another of the three critical care founders, William Shoemaker. The two were members of the Departments of Surgery and Anesthesiology at the USC, and it was our privilege to share their stories and wisdom. Dr. Buchman's foreword recognizes the third partner in critical care's foundation, Dr. Peter Safar; together, these three individuals helped develop the specialty we now recognize, and we hope this *Atlas* reflects well on their creative genius and groundbreaking, transformative innovation.

Critical care medicine has a multidisciplinary past, present, and future; it is multi-professional, team based, and uniquely positioned at the interfaces of anesthesiology, medicine, nursing, pediatrics, pharmacy, respiratory therapy, and surgery, requiring complementary expertise from all participants and consultants in order to effect positive patient outcomes. The practice of critical care relies on invasive techniques from mechanical ventilation to ECMO as well as on invasive monitoring modalities required to ensure appropriate life support functions. In many cases quasi-surgical/invasive techniques are required to establish airway, vascular access and mitigate complications. While expertise abounds in all primary disciplines, the *Atlas of Critical Care* engages procedural experts and utilizes their experience to produce a guide for all practitioners to view the insertion and management of most frequently used life support and monitoring techniques.

Why is such an atlas important today? It is primarily because of the nature of our specialty and the manner in which it is practiced. The techniques may be performed by a single operator, but all require assistance and understanding the physiologic and anatomic placement implications of the device itself: e.g., erosion of an adjacent major vessel, delayed pneumothorax, pulmonary embolism, and impeller rotor failure. Therefore, all members of the team must be familiar with the anatomy of the device as well as the patient, and the *Atlas* provides a procedurally based approach designed for not only the operators and inserters but also the maintainers and assisters who will develop a greater understanding of the device as well as troubleshooting its complications.

The *Atlas of Critical Care* is a multidisciplinary and interdisciplinary resource that motivates and enables more appropriate insertion, management, and troubleshooting of the technically and technologically advanced devices that make the delivery of critical care possible.

Los Angeles, CA
Philip D. Lumb

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Part I

Airway

Endotracheal Intubation: Oral and Nasal

1

Gillian Morrison and Joshua M. Tobin

1.1 General Principles

- The indications for airway management include protecting the airway from aspiration, providing adequate oxygenation, and providing adequate ventilation (removing carbon dioxide).
- Adequate preoxygenation is the key principle to avoiding desaturation during the apneic period associated with rapid sequence induction. Patients should breathe 10 L of oxygen for 2 min or five vital capacity breaths, prior to induction.
- Simple airway examination can help to determine the likelihood of a difficult airway. A difficult airway is suggested by Mallampati (MP) score III or IV, thyromental (TM) distance <6 cm, limited range of motion of the cervical spine, small chin, overbite, short thick neck, pathology of the airway, and radiation to the neck.

  Mallampati score when looking into an open mouth:
  I = able to visualize all of the soft palate
  II = able to visualize all of the uvula
  III = able to visualize only the base of the uvula
  IV = soft palate not visible
- Further predictors of difficulty with mask ventilation include beard, obesity, no dentition/edentulous, and history of obstructive sleep apnea (OSA).
- In the event that a potentially difficult airway is identified, then consider expert consultation immediately.
- The usual size of endotracheal tube used is a #7.0 for adult women and #7.5 for adult men.
- Endotracheal tube size for children = (age/4) + 4.
  Children have a more superior and anterior larynx.
  The pediatric epiglottis can be larger and more “floppy”; therefore consider the use of a Miller (straight) blade.

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1.2 Equipment (Fig. 1.1)

- Endotracheal tube (ETT): usual size in women (#7), men (#7.5–8), and children (size = [age/4] + 4).
- Nasopharyngeal airway (NPA).
- Oropharyngeal airway (OPA).
- Laryngoscope: the two main types of laryngoscope blade are Macintosh (curved blade designed to be placed in the vallecula) and Miller (straight blade designed to manipulate the epiglottis).
- Gum elastic bougie.
- Bag valve mask (BVM) ventilator bag.
- Laryngeal mask airway (LMA): usual size for 70 kg adult = #4
- Magill forceps.
- Fiber-optic bronchoscope (FOB).

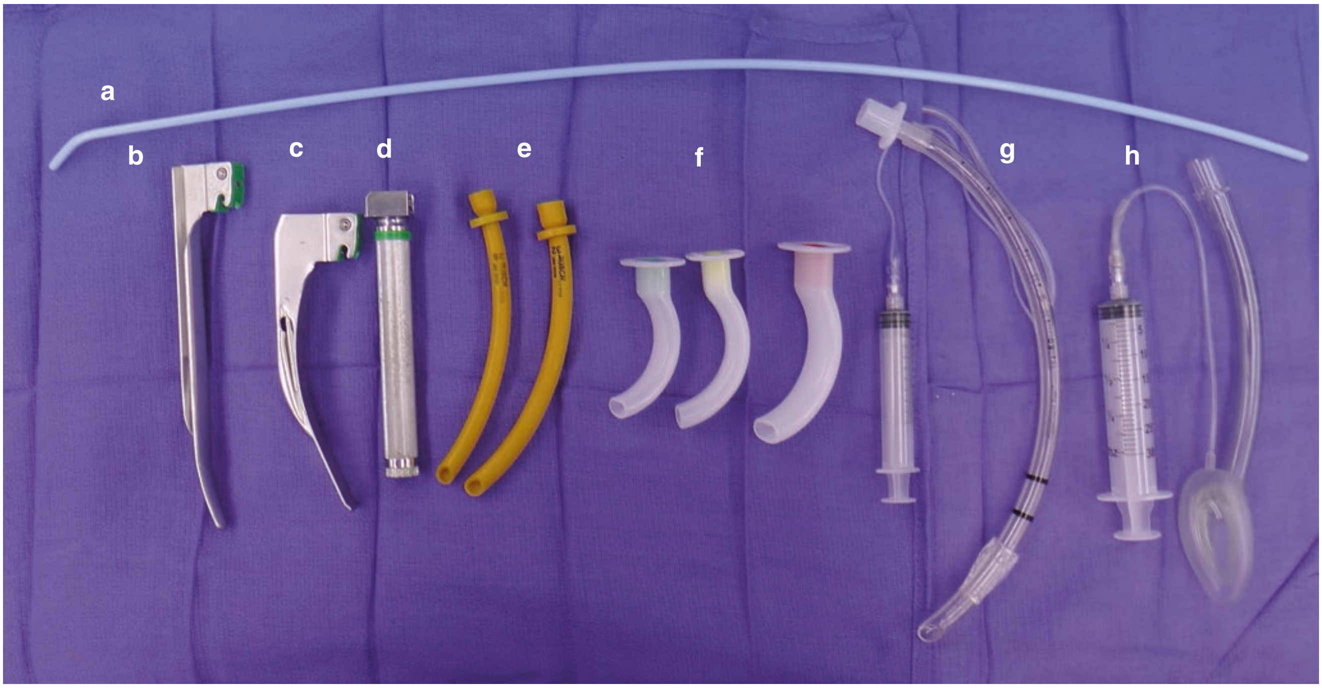

Fig. 1.1 Equipment setup: (**a**) gum elastic bougie, (**b**) Miller blade (straight), (**c**) Macintosh blade (curved), (**d**) laryngoscope handle, (**e**) nasopharyngeal airways (various sizes), (**f**) oral airways (various sizes), (**g**) oral endotracheal tube with stylet and syringe to fill cuff, (**h**) laryngeal mask airway with syringe to fill cuff

1.3 Technique

1.3.1 Positioning

- Sniffing position: to optimize laryngoscopy the neck is slightly flexed and the head extended to help align the oral, pharyngeal, and laryngeal axes. It helps to have the external auditory meatus and the sternum in the same horizontal plane.
- The patient should be positioned such that they are as close to the head of the bed as possible (i.e., close to the laryngoscopist).
- Bed height should be adjusted to the level of the laryngoscopist's xyphoid process to allow optimal visualization of the larynx.

1.3.2 Oropharyngeal Airway Management (Fig. 1.2a–c)

- Sized from the corner of the mouth to the ear or middle of the mouth to angle of mandible
- Normal adult size #7–9
- Placed gently in the airway; either approximating the gentle curvature of the oropharynx or inserting concave up (i.e., toward the nose) and gently rotating the OPA as it is inserted

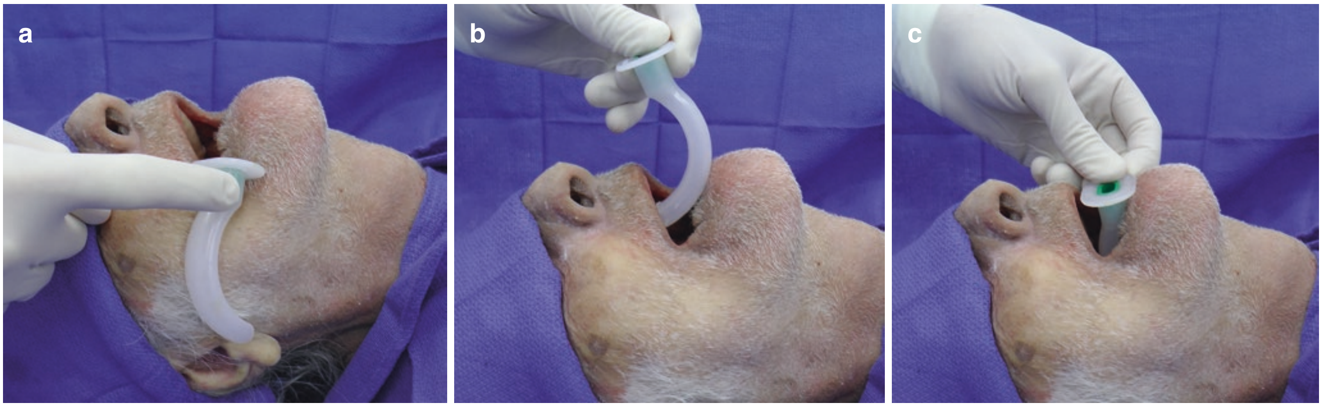

Fig. 1.2 Oropharyngeal airway management: (**a**) appropriate size is chosen by matching the length of the OPA from corner of the lip to angle of the mandible; (**b**) to insert OPA, first insert oral airway in "upside-down" position until halfway into the mouth, and then rotate 180 degrees as OPA is fully advanced into the mouth; (**c**) gently advance the OPA until the flange is at the lips

1.3.3 Nasopharyngeal Airway Management (Fig. 1.3a, b)

- Sized from tip of the nose to the earlobe.
- Normal adult size 28–32 French.
- Gently pass well-lubricated NPA via the larger of the two nares, being certain to pass the NPA along the gentle curvature of the nasopharynx rather than superiorly toward the turbinates.

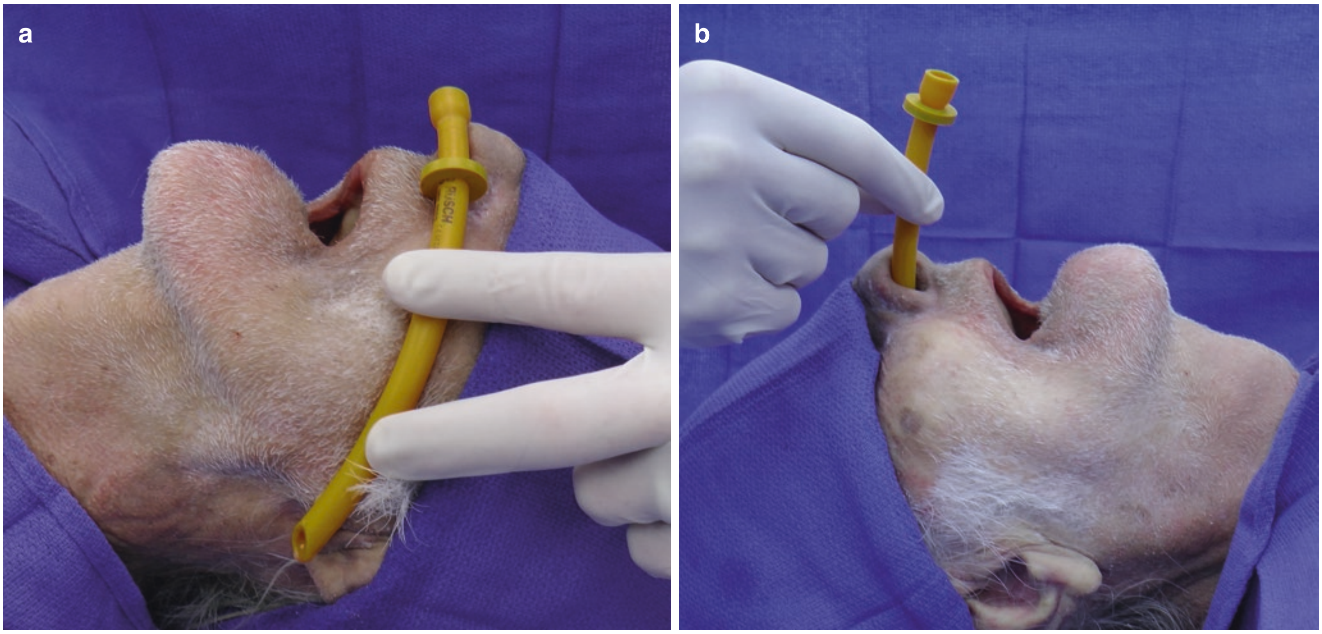

Fig. 1.3 Nasopharyngeal airway management: (**a**) appropriate size is chosen by measuring from tip of the nose to angle of the mandible. The largest diameter that will fit should be used; (**b**) insert NPA in posterior direction along floor of nasal cavity

1.3.4 Mask Ventilation

- The face mask should have a tight seal with good skin-face contact, such that oxygen from the BVM is directed only to the patient and does not leak to the environment.
- When mask ventilating patient, observe rise with each positive pressure breath delivered as well as "misting" (i.e., humid exhaled air) in the face mask during each exhalation.
- Assisted ventilation can be used to augment a patient's tidal volume when the patient is still taking spontaneous pressure breaths. Assist each breath with positive pressure applied from the BVM.
- Hold the mask on the patient's face with the "C-E hand position" (see Fig. 1.4a, b). With the middle, ring, and pinky fingers in the shape of an E, place fingers along the mandible to lift the jaw up and into the face mask. With the thumb and index finger in the shape of a C, hold the mask tightly sealed against the patient's face. During spontaneous breathing, each time the patient initiates a breath, squeeze the BVM gently to augment the tidal volume. This is a useful technique if a patient is in respiratory distress and the laryngoscopist is pre-oxygenating while waiting for induction medications, airway equipment, etc.

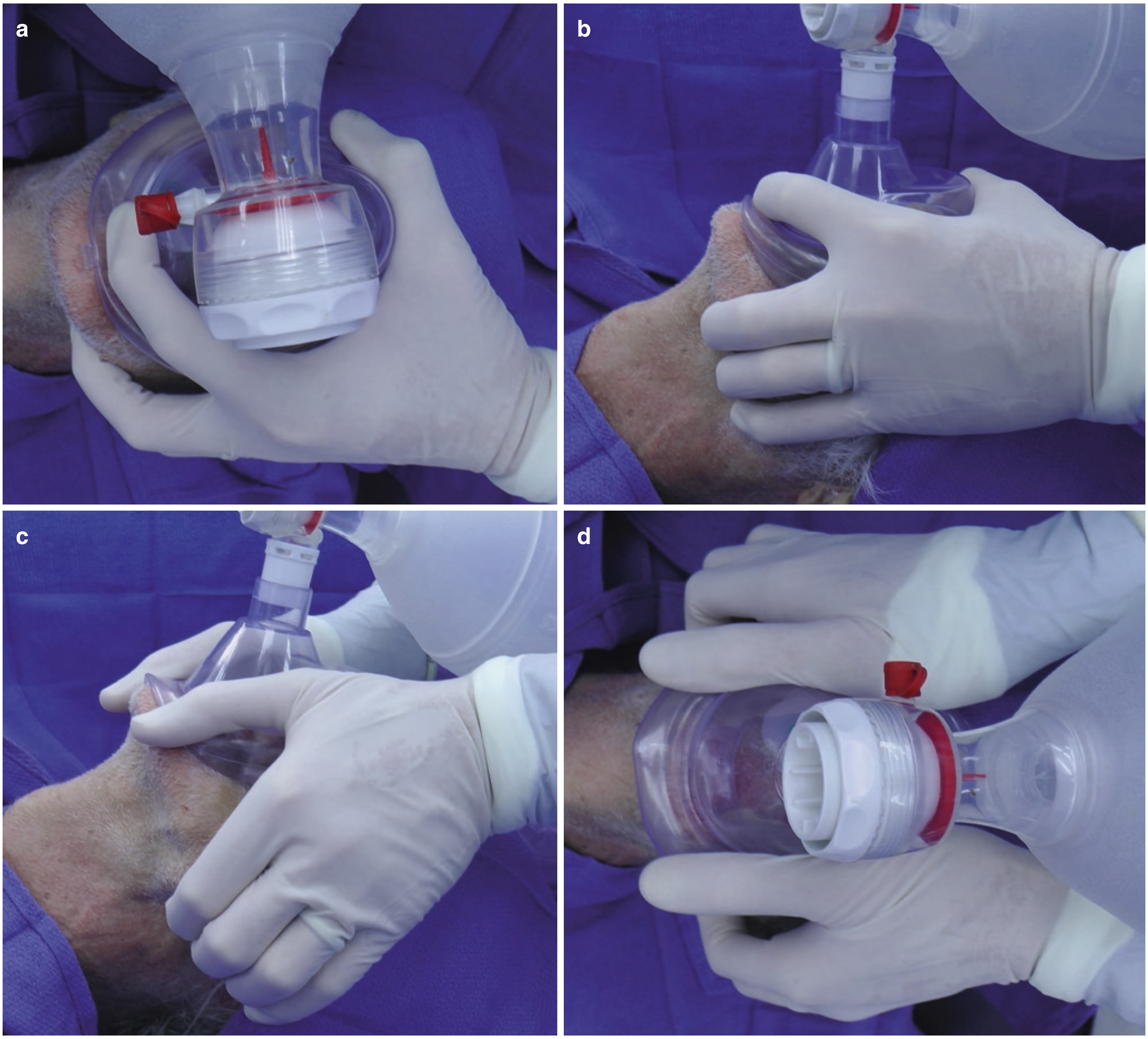

Fig. 1.4 Mask ventilation: (**a**) the "C-E clamp" (from above); (**b**) one-handed mask ventilation using the C-E clamp (lateral view). The "E" should lift the jaw up toward the mask, while the "C" maintains a tight seal between the face and the mask; (**c**, **d**) two-handed ventilation (view from above and lateral view)

1.3.5 One-Hand Ventilation (Fig. 1.4a, b)

- Most common method to ventilate patient.
- A tight seal is accomplished using the “C-E hand position” (as above).
- After induction, or once patient is no longer taking spontaneous respirations, the left hand holds the face and mask in the “C-E hand position,” and the right hand squeezes the BVM to deliver the desired tidal volume. Ensure that, with each positive pressure breath given, adequate chest rise is seen and “misting” appears in face mask after each exhalation.

1.3.6 Two-Hand Ventilation (Fig. 1.4c, d)

- Technique requires two people and is utilized when the patient is difficult to ventilate using the one-hand technique. Two-hand ventilation allows laryngoscopist to apply tighter skin-face contact.
- One person performs jaw thrust using fingers on either side of the mandible with the thumbs providing a tight seal with the face mask. The second person squeezes the BVM to deliver the desired tidal volume.

1.3.7 Direct Laryngoscopy (DL) (Fig. 1.5)

- Laryngoscopist looks directly at the patient’s larynx to visualize the vocal cords and watch the endotracheal tube pass through the vocal cords.
- Patient must be positioned in a “sniffing position” such that the oral, pharyngeal, and laryngeal axes align as closely as possible. This is best accomplished by positioning the patient with the neck slightly flexed and the head slightly tilted backward/extended (i.e., as if the patient were “sniffing a flower”).
- In the event that cervical spine clearance has not been obtained (i.e., there is a risk of potential spinal fracture or spinal cord injury), then minimize movement of the neck during intubation with manual in-line stabilization of the neck in a neutral position.
- The Macintosh blade is the most common blade used for direct laryngoscopy.
- Open the patient’s mouth with the right hand using a “scissoring motion” (Fig. 1.6a) (i.e., apply gentle pressure to the lower incisors/premolars/jaw in order to open the mouth). Be certain that while opening the patient’s mouth, the sniffing position is maintained. Avoid applying pressure to the incisors/jaw area (Fig. 1.6b), as this does not provide sufficient mouth opening to accommodate easy passage of the laryngoscope blade.
- Hold laryngoscope in the left hand, and use the Macintosh blade to sweep the patient’s tongue from right to left, such that the tongue is displaced to the left side (Fig. 1.5a).
- Advance the Macintosh blade until tip of the blade is in vallecula.
- Lift laryngoscope to visualize vocal cords, being careful not to rotate the laryngoscope back onto patient’s teeth.
- When vocal cords are visualized, pass endotracheal tube through the vocal cords. Do not interrupt visualization of the vocal cords until tube is visualized passing through cords.
- Once tip of ETT is through cords, have stylet removed by assistant and then advance tube to correct depth.
- Verify end-tidal carbon dioxide (ETCO$_2$) using either a side-stream analyzer or colorimetric device. Also verify bilateral breath sounds and absence of breath sounds over the epigastrium.

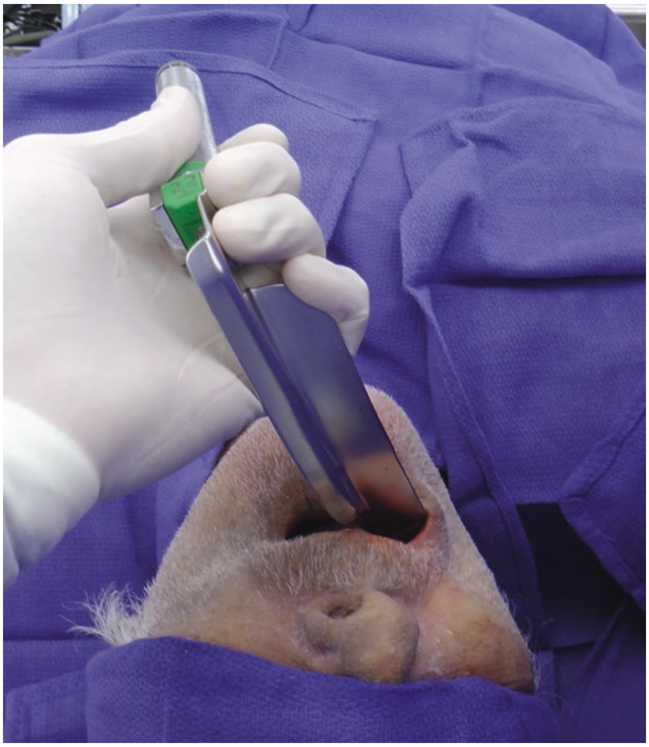

Fig. 1.5 Direct laryngoscopy: insert blade of laryngoscope along the right side of the mouth, sweeping the tongue to the left side of the mouth

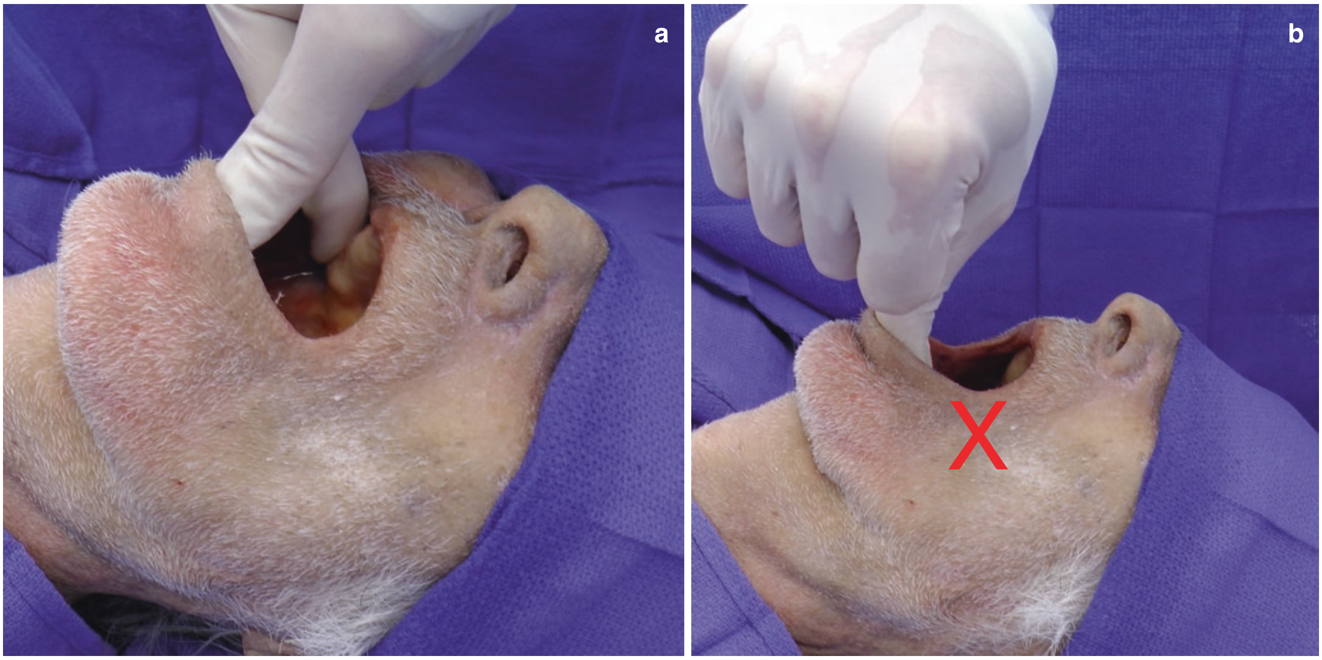

Fig. 1.6 Premolar push/scissoring the mouth open: (**a**) apply gentle pressure on premolars to open the mouth with a "scissoring" motion; (**b**) do not place digits on incisors to open the mouth

1.3.8 Bougie-Assisted Direct Laryngoscopy

- The bougie is useful during laryngoscopy if the laryngoscopist is unable to visualize the vocal cords during laryngoscopy.
- The tactile sensation of the bougie tip running along the tracheal rings (similar to a stick being run along a fence) gives the laryngoscopist tactile feedback that the bougie is within the trachea.
- Insert bougie into the mouth with angled coudé tip facing upward.
- The curved tip should contact the epiglottis as it is passed under the epiglottis and into the trachea. On insertion into the trachea, the bougie encounters the tracheal rings, which produce a distinct sensation to the laryngoscopist as the tip "runs over" individual rings. Once this feel is confirmed, the endotracheal tube can be inserted with confidence over the bougie to an appropriate depth; occasionally, and most commonly in cases of an anterior larynx, it may be necessary to rotate the tube gently to pass into the glottic opening without trauma. Some practitioners prefer to leave the laryngoscope in situ during endotracheal tube insertion to facilitate the procedure.
- Regardless of preference, the ETT is then passed over the bougie and into the trachea. Once the ETT is at an appropriate depth, the bougie is withdrawn.
- Verify $ETCO_2$ in the usual fashion.

1.3.9 Laryngeal Mask Airway (Fig. 1.7a–c)

- The laryngeal mask airway (LMA) is a supraglottic airway (i.e., it does not pass through the vocal cords). It is not a secure airway. Laryngospasm can obstruct airflow, such that it may not be possible to ventilate with the LMA.
- In the ICU, the LMA is best reserved as part of the emergency airway algorithm, for example, during "can't intubate, can't ventilate" cases or when urgent ventilation is required.
- LMA size is chosen base on patient's weight, and each LMA package will specify the weight for which the size is indicated. A typical size for a 70 kg adult is size #4.
- Open the patient's mouth by using the left hand to lift up the mandible. Ensure that the part of the LMA that will abut the hard palate is well lubricated prior to insertion.
- Hold the LMA in the right hand as shown (Fig. 1.7a), and use the index finger to guide the LMA along the hard palate and over the tongue (Fig. 1.7b). The LMA will "pop" into place as it passes the base of the tongue and is seated over the larynx (Fig. 1.7c).
- If the LMA is positioned correctly, one should be able to give positive pressure breaths, see chest rise, and hear minimal gas leak at 20 cm H_2O.
- Rescue technique:

  The LMA is useful in "can't intubate, can't ventilate" situations.

  Placement of an LMA may allow adequate gas exchange. If that is not possible, then surgical airway management with cricothyroidotomy is indicated.

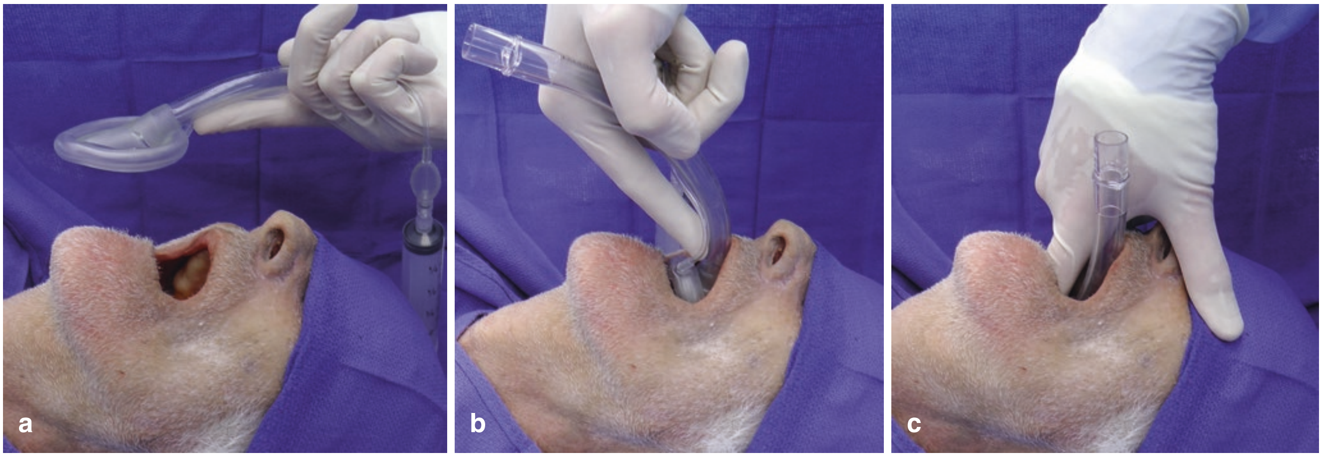

Fig. 1.7 LMA insertion: (**a**) hold LMA in the right hand as shown; (**b**) guide LMA along the roof of the mouth into the pharynx; (**c**) LMA will "pop" into place as it passes the base of the tongue and is seated over the larynx

1.3.10 Video Laryngoscopy (VL) (Figs. 1.8, 1.9, 1.10, 1.11, and 1.12)

- Video laryngoscopy is a method that uses a fiber-optic camera integral to a modified laryngoscope blade to indirectly visualize the glottis during endotracheal intubation.
- While video laryngoscopy does not improve the likelihood of intubation success on first-attempt in ICU patients compared to direct laryngoscopy, VL is a safe method to intubate patients with cervical spine injuries.
- The video laryngoscope is held in the left hand, and the scope is inserted into the mouth at the midline, without need to laterally displace the tongue with the scope.
- When the glottis is visualized on the screen, the styleted endotracheal tube is inserted through the mouth, and the video screen is used to guide the tube through the cords and into the trachea.
- Once tip of ETT is through cords, have the stylet removed by an assistant, and advance the ETT to the correct depth.
- Advantages of using the VL: it is unnecessary to align oral, pharyngeal, and laryngeal axes, which may be useful for patients with limited range of cervical motion.

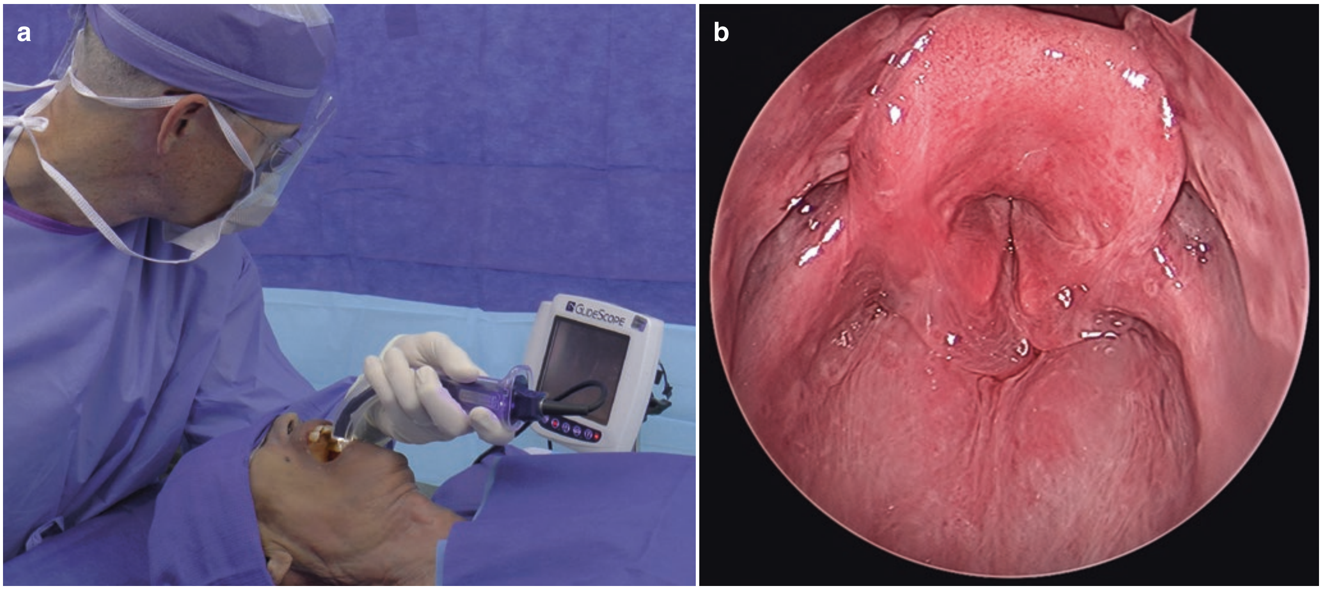

Fig. 1.8 The tip of the VL is inserted into the mouth; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

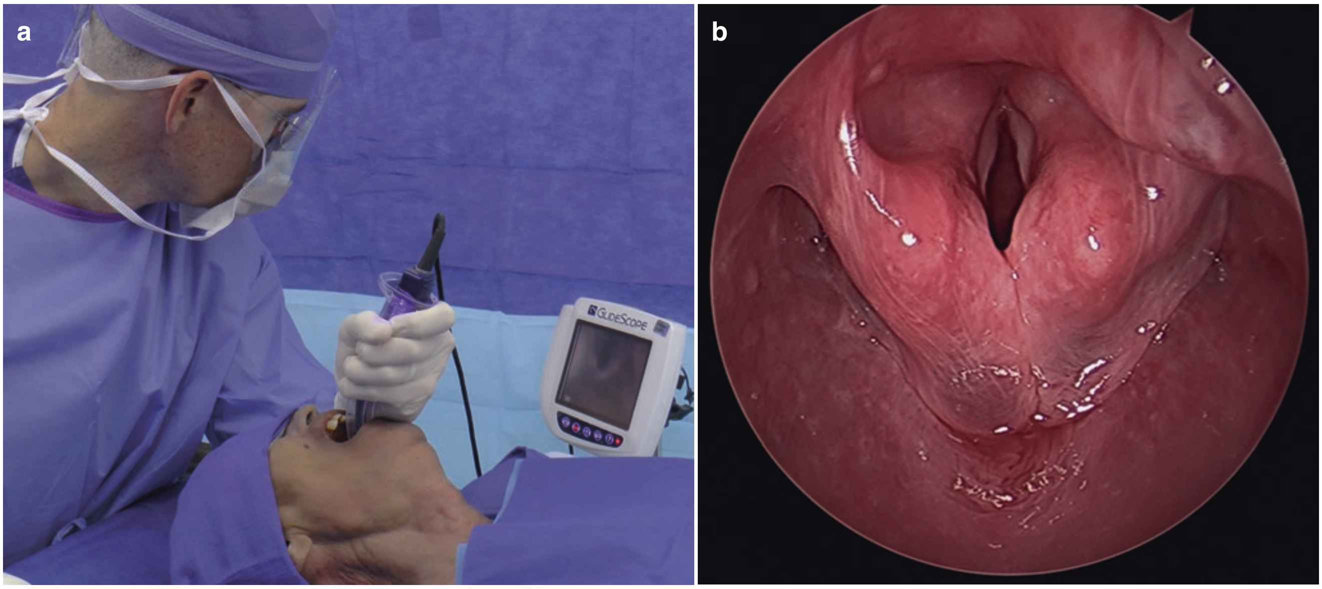

Fig. 1.9 The VL is inserted fully into the oropharynx, and the vocal cords are visualized; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

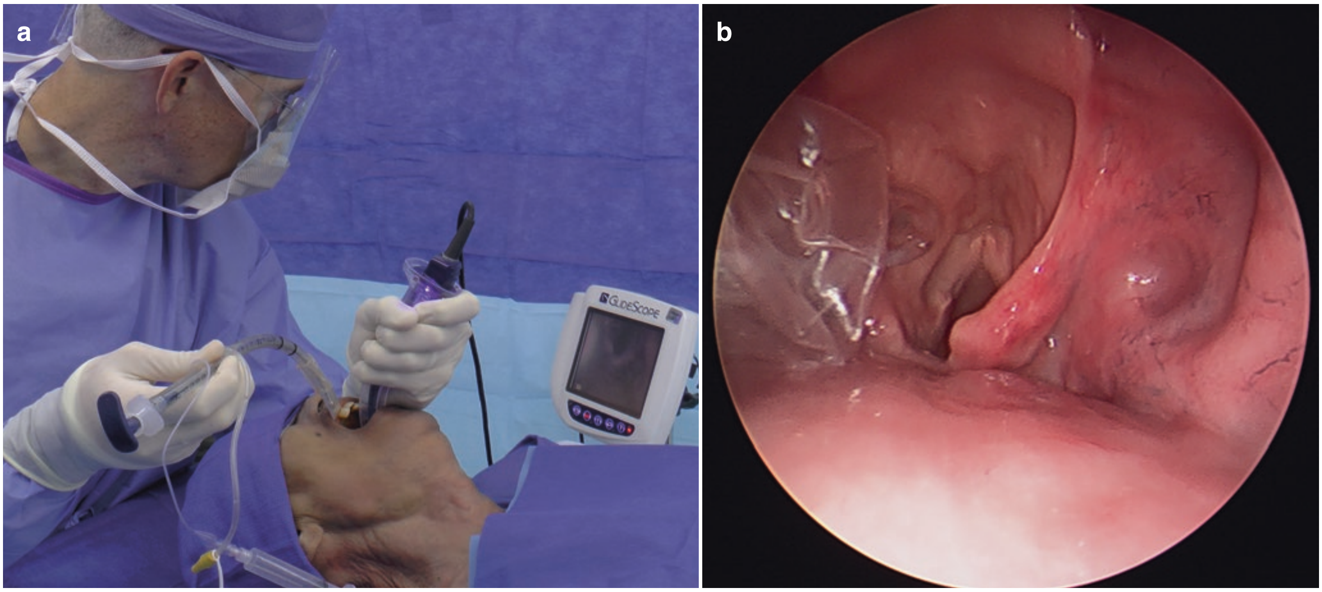

Fig. 1.10 A styleted endotracheal tube is inserted from the side while maintaining visualization of the vocal cords on the VL screen; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

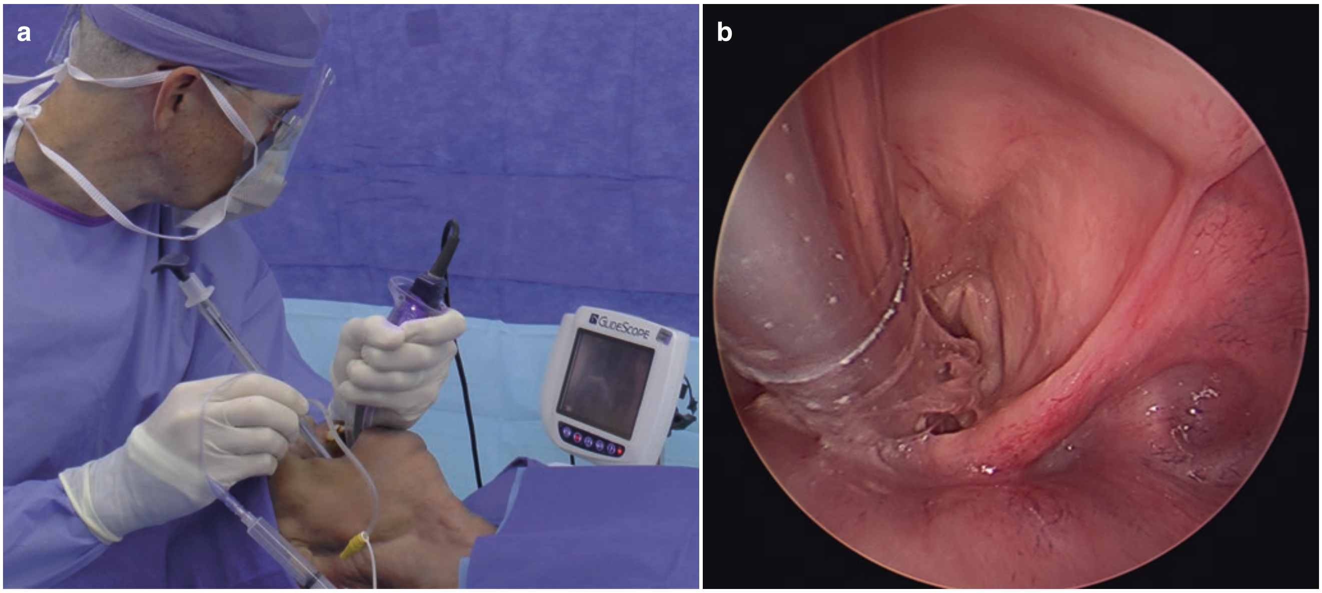

Fig. 1.11 The endotracheal tube is guided through the vocal cords and into the trachea; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

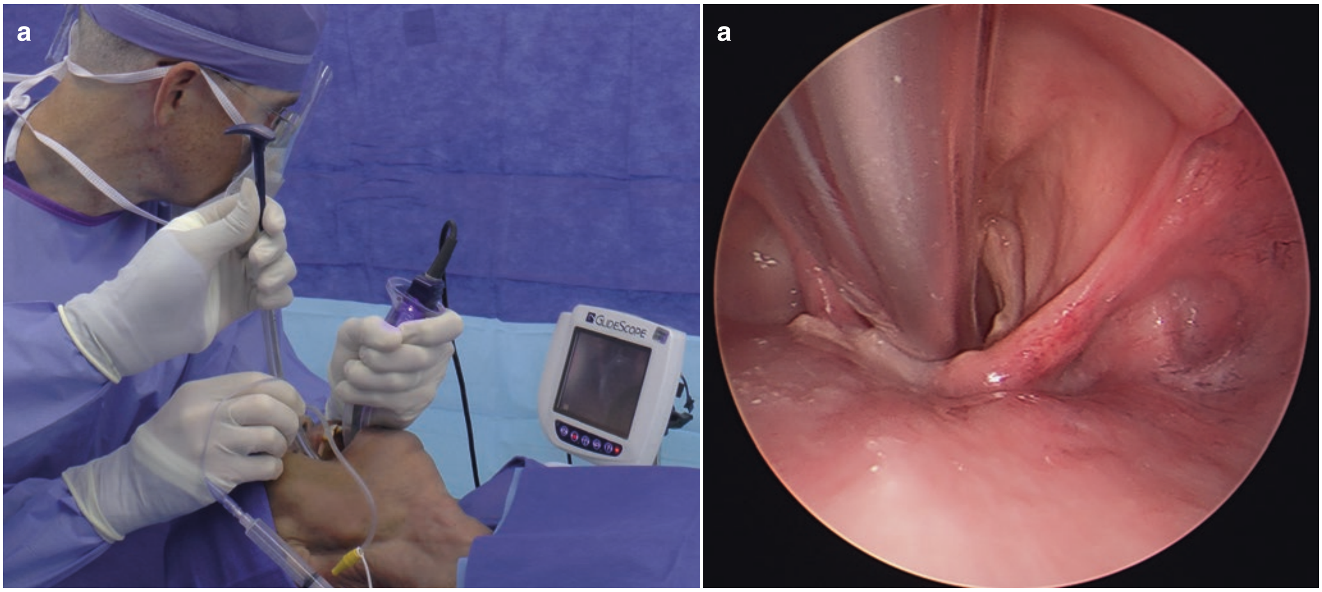

Fig. 1.12 An assistant removes the stylet, while the laryngoscopist holds the endotracheal tube; (**a**) external view (i.e., instrument positioning); (**b**) internal view (i.e., view on screen of instrument)

1.3.11 Nasal Intubation

- Indications for nasal intubation include patients in whom access to the oropharynx is limited (e.g., unable to open the mouth, jaw "wired shut", etc.).
- It is important to select the correct size for the nasoendotracheal tube (NETT), as the diameter of the NETT is proportional to its length. The curvature of the NETT is designed to accommodate the nasopharynx but can also limit its depth of insertion.
- Prior to nasal intubation, the nares should be treated with a topical vasoconstrictor (e.g., phenylephrine) to reduce bleeding. The nasal passage should also be lubricated and can be dilated with a nasopharyngeal airway prior to insertion of nasal endotracheal tube.
- The NETT should be warmed/softened prior to use. This can be accomplished by immersing the NETT in warm saline for several minutes prior to use.
- The NETT should then be well lubricated to minimize trauma to the nasal mucosa while being inserted.

1.3.11.1 Technique

- After preparing the nasopharynx as described above, insert NETT into nares. With gentle pressure, direct the tube in a posterior inferior direction along the floor of the nasal cavity toward the pharynx (Fig. 1.13). If resistance is met, then gentle rotation of the tube and redirection can facilitate passing the NETT.
- Continue passing tube until the natural bend in the NETT is at the tip of the nose.
- One can "blindly" pass the NETT, as the NETT will sometimes naturally enter the trachea rather than the esophagus. This must be confirmed with an ETCO$_2$ detector in the usual fashion.
- Alternatively, the NETT can be passed until it remains just above the vocal cords (as evidenced by audible respirations and humid expirium/mist in the NETT). The FOB can then be passed through the NETT. Commonly the vocal cords will be visualized just beyond the end of the NETT.
- Using slow gentle movements, pass the FOB through the vocal cords, enter the trachea, and advance the FOB until the carina is visualized. The NETT is then gently passed over the FOB, and the FOB is withdrawn.
- ETCO$_2$ is confirmed in the usual fashion.
- A final alternative is to insert NETT as above, but after the NETT is approximately halfway inserted, perform either VL or DL.
- Use Magill forceps to grasp the NETT that is now in the posterior pharynx, being careful to avoid touching/damaging the balloon. Thread the tip of NETT through the vocal cords.

1.3.12 Tips and Pitfalls

- n.b.: Do not use a NPA in cases of expected skull base fracture!
- n.b.: False-positive ET CO$_2$ values can be noted in the first 2–3 breaths after endotracheal intubation if there are carbonated beverages in the stomach!
- n.b.: Children may have a larger and more "floppy" epiglottis; therefore, consider the use of a Miller (straight) blade!
- n.b.: If there is any doubt regarding possible cervical spine injury, then use manual in-line stabilization!
- n.b.: Always have a backup plan; remember that any needed airway equipment must be within arm's reach!

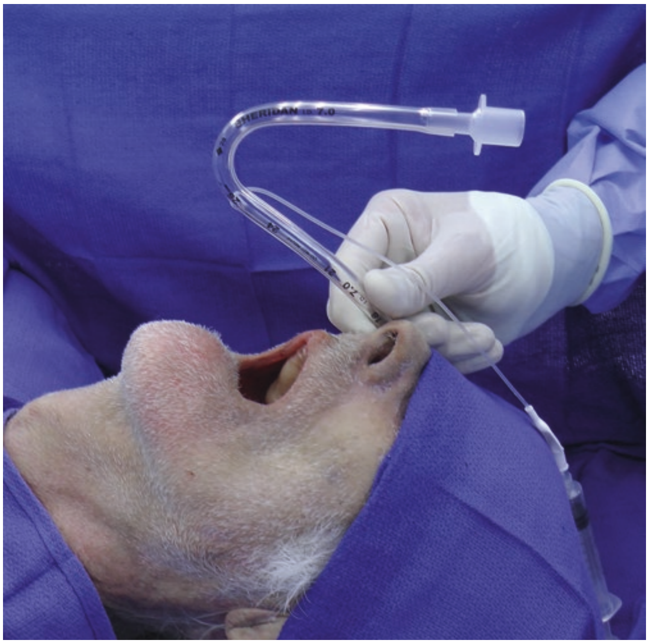

Fig. 1.13 With gentle pressure, direct the NETT along the floor of the nasal cavity toward the pharynx

Percutaneous Tracheostomy

2

Morgan Schellenberg and Kenji Inaba

2.1 Surgical Anatomy

- Please refer to Chapter 3, Open Tracheostomy, Surgical Anatomy.

2.2 General Principles

- Tracheostomy is a bedside procedure performed in the intensive care unit for patients requiring prolonged mechanical ventilation or who require long-term airway protection. Specific indications include prolonged respiratory failure, high spinal cord injury, traumatic brain injury, and stroke. Tracheostomies can also be required as an adjunct for tracheal injuries, but these are typically performed in the operating room using the open technique.
- Tracheostomy can be performed using an open or percutaneous technique. Although both techniques can be considered in the majority of clinical situations, percutaneous tracheostomy is relatively contraindicated in patients with cervical spine fractures, patients on systemic anticoagulation, and patients with altered anatomy due to obesity, previous neck surgery, or radiation.
- Percutaneous tracheostomy requires the concurrent use of bronchoscopy and therefore cannot be performed if bronchoscopy is unavailable. Note that percutaneous tracheostomy requires three healthcare providers: the operator, the bronchoscopist, and a circulator.
- When compared to open tracheostomy performed in the operating room (OR), the benefits of percutaneous tracheostomy include lower cost, the lack of need to transport patients, and the avoidance of OR resource consumption.

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2.3 Patient Positioning

- The patient should be positioned with the neck fully extended in order to bring the trachea into the anterior position (Fig. 2.1). A roll should be placed behind the patient's shoulders to facilitate this, and the head can be stabilized with the use of a ring cushion.

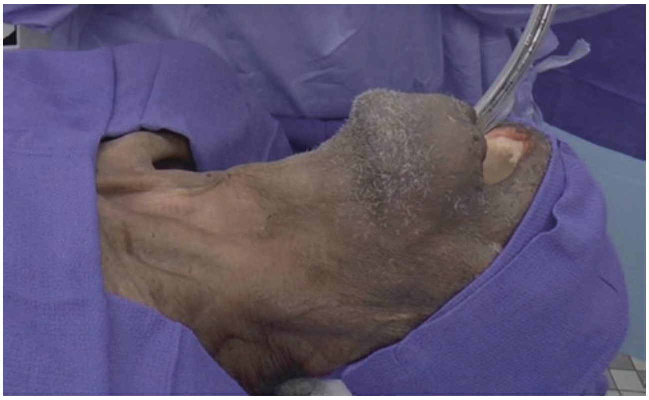

Fig. 2.1 Patient positioning and draping for percutaneous tracheostomy. If the cervical spine has been cleared, the neck should be fully extended to bring the trachea into the anterior position. The entire neck, including the lower aspect of the mandible and upper chest, should be exposed, prepped, and draped

- The entire neck, including the lower aspect of the mandible and upper chest, should be exposed, prepped, and draped (Fig. 2.1) to provide adequate room to work and facilitate surface landmark identification.

2.4 Special Instruments

- The percutaneous technique can be performed with a variety of commercially available kits, which include a scalpel, catheter over hollow-bore needle, syringe, guidewire, guiding catheter, dilators, and introducers for the tracheostomy tube (Fig. 2.2). We prefer a single dilation system.
- A range of tracheostomy tube sizes should be available. We typically place a 6.0–7.0 mm internal diameter (ID) tube for women and a 7.0–8.0 mm ID tube for men. Tubes with a proximal extension should be considered for patients with thick or full necks, and a distal extension can also be used if required.
- Once the appropriately sized tracheostomy tube has been selected, it should be pre-loaded over the correspondingly sized tracheostomy loading dilator provided in the kit. Before beginning the procedure, ensure the tracheostomy tube cuff is intact by inflating it with air.
- The necessary equipment to convert to open tracheostomy (refer to Chapter 3, Open Tracheostomy) should be available at the bedside.
- Bronchoscopy equipment and a second physician to operate the bronchoscope are essential. A video bronchoscope setup allows the operator to view the procedure as well and is highly recommended.
- The patient must have an endotracheal tube in place that is at least 7.5 mm ID to allow for ventilation to occur around the bronchoscope during the procedure.
- A suction catheter for the tracheostomy, appropriate lighting, and an end-tidal CO_2 detector should be available.

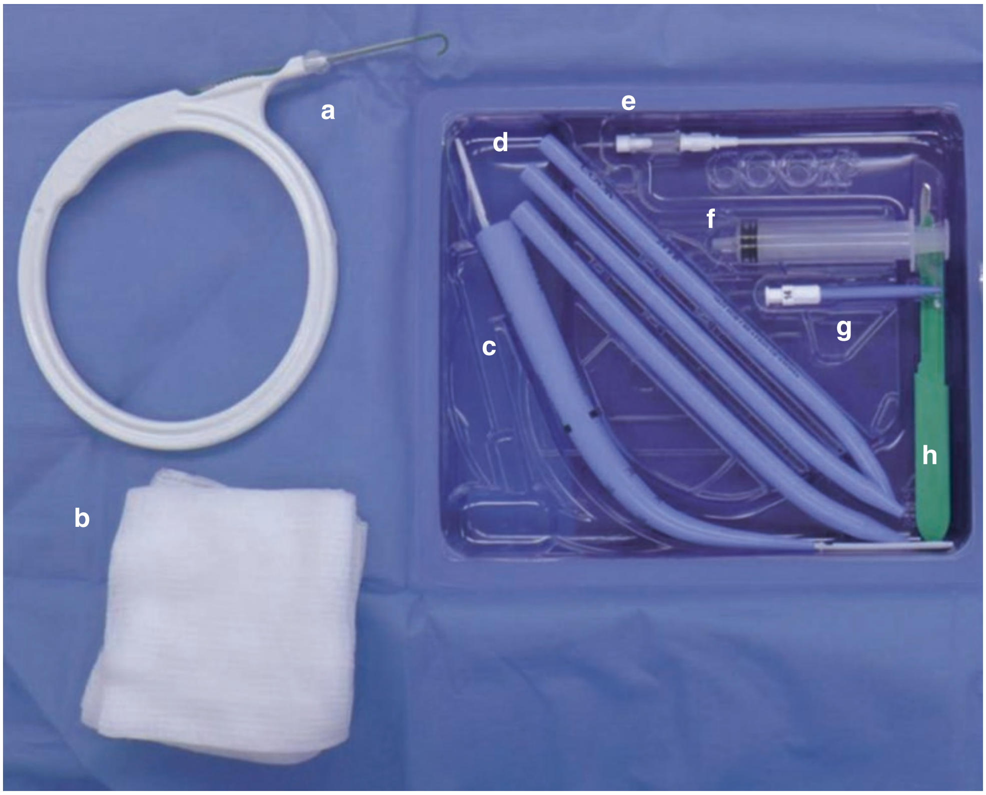

Fig. 2.2 Commercially available percutaneous tracheostomy kit. a, Guidewire. b, Gauze. c, Percutaneous tracheostomy dilator (*blue*) with guiding catheter (*white*). d, Tracheostomy loading dilators (3). e, Catheter over hollow-bore needle. f, Syringe. g, 14 Fr dilator. h, Scalpel

2.5 Technique

- The percutaneous technique begins in the same manner as the open technique. Start by identifying the thyroid cartilage, cricoid cartilage, and sternal notch (refer to Chapter 3, Open Tracheostomy). Use a 15 blade to make a 2–3 cm transverse incision through the skin approximately 2 fingerbreadths above the sternal notch, centered in the midline (Fig. 2.3a).
- Palpate the trachea deep to the subcutaneous tissue through the skin incision created. Use gentle blunt dissection with a Kelly clamp to dissect down onto the anterior surface of the trachea (Fig. 2.3b), and locate the second and third tracheal rings.
- Insert the bronchoscope through the endotracheal tube, and withdraw the endotracheal tube until it is located immediately proximal to the planned site of entry into the trachea. The operator can ballot the planned site of tracheostomy to help visualize this area.
- Use the catheter over a hollow-bore needle connected to a syringe filled with normal saline, and insert this into the airway through the skin incision at a 45 degree angle, pointed toward the carina. Entry into the airway will be both felt as a loss of resistance and visualized through the bronchoscope (Fig. 2.3c). Air can also be aspirated once within the trachea (Fig. 2.3d), providing a third means of confirming entry into the airway.
- The needle should be inserted into the trachea in the midline, represented by the 12 o'clock position when visualized through the bronchoscope. This prevents eccentric placement and helps avoid injury to the back wall of the trachea.
- Ensure the needle does not injure the bronchoscope when it is introduced into the trachea. The endotracheal tube should shield the bronchoscope and may need to be slowly retracted by the bronchoscopist.
- Under direct vision with the bronchoscope, remove the syringe and needle, leaving the catheter in place in the airway. Feed the guidewire into the airway through the catheter (Figs. 2.4 and 2.5a). Ensure bronchoscopically that the wire passes toward the carina and not upward to the larynx. Once the wire is in the trachea, remove the catheter.
- Next, use the serial dilators in the kit to widen the opening into the trachea. The 4.5-cm-long 14 Fr dilator should first be advanced into the airway over the wire and visualized within the lumen of the trachea bronchoscopically (Fig. 2.5b). After this, use the single size percutaneous tracheostomy dilator with the guiding catheter positioned within it to dilate the opening further (Fig. 2.5c). Use the image through the bronchoscope to do this under direct visualization throughout to ensure the posterior tracheal wall is not damaged (Fig. 2.5d).
- Remove the dilator but leave the guiding catheter over the wire, positioned in the airway (Fig. 2.5e). Insert the tracheostomy tube, preloaded over the appropriately sized tracheostomy loading dilator, over the guiding catheter and wire into the airway (Fig. 2.5f, g). The tube should be initially inserted straight back into the tracheal lumen and then directed toward the carina to pass it completely into the airway. Visualize the insertion with the bronchoscope.
- Remove the wire, guiding catheter, and tracheostomy loading dilator together. Inflate the cuff of the tracheostomy tube and suction out any secretions from the airway. Commence ventilation through the tracheostomy, and remove the endotracheal tube. Finally, suture the tracheostomy to the skin in four quadrants using 0 prolene suture (see Chapter 3, Open Tracheostomy).

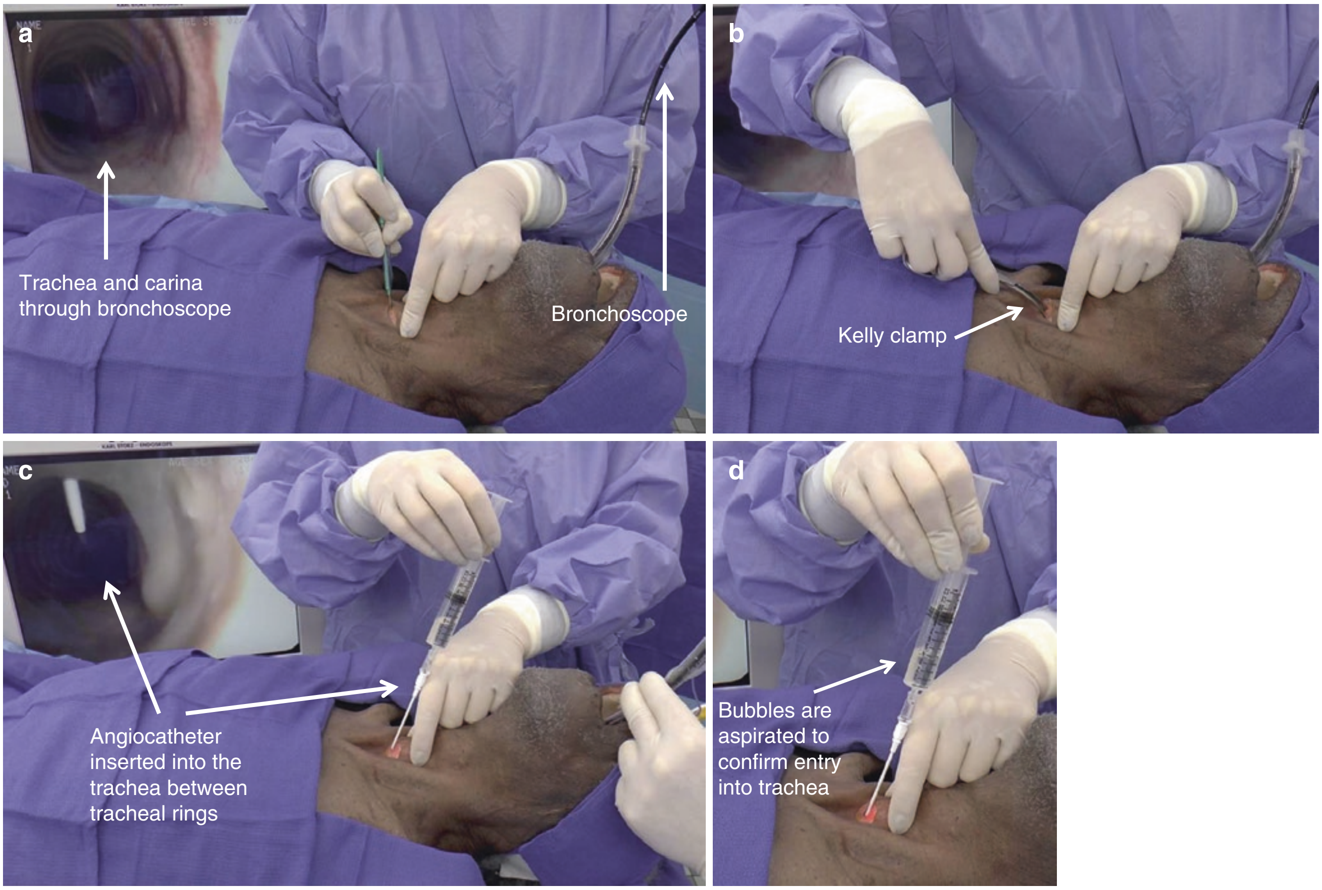
a
Trachea and carina through bronchoscope
Bronchoscope
b
Kelly clamp
c
Angiocatheter inserted into the trachea between tracheal rings
d
Bubbles are aspirated to confirm entry into trachea

Fig. 2.3 (**a**–**d**) Steps of the percutaneous tracheostomy technique. Identify the thyroid cartilage, cricoid cartilage, and sternal notch. Use a 15-blade to make a 2-3 cm transverse skin incision in the midline, approximately 2 fingerbreadths above the sternal notch (**a**). Dissect down onto the anterior surface of the trachea (**b**), and locate the second and third tracheal rings. Insert the bronchoscope through the endotracheal tube and withdraw the endotracheal tube until it is located immediately proximal to the planned site of entry into the trachea. Use the catheter over a hollow-bore needle connected to a syringe filled with normal saline and insert this into the airway through the skin incision at a 45° angle, pointed towards the carina. Entry into the airway will be both felt as a loss of resistance and visualized through the bronchoscope (**c**). Air can also be aspirated once within the trachea (**d**)

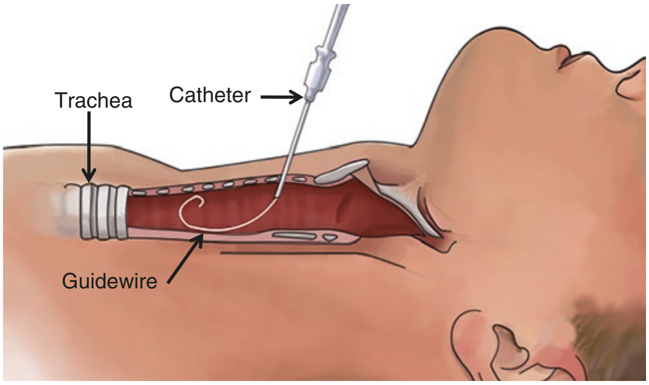

Fig. 2.4 Sagittal view of the airway during percutaneous tracheostomy. Through the catheter in the trachea, feed the guidewire into the airway towards the carina

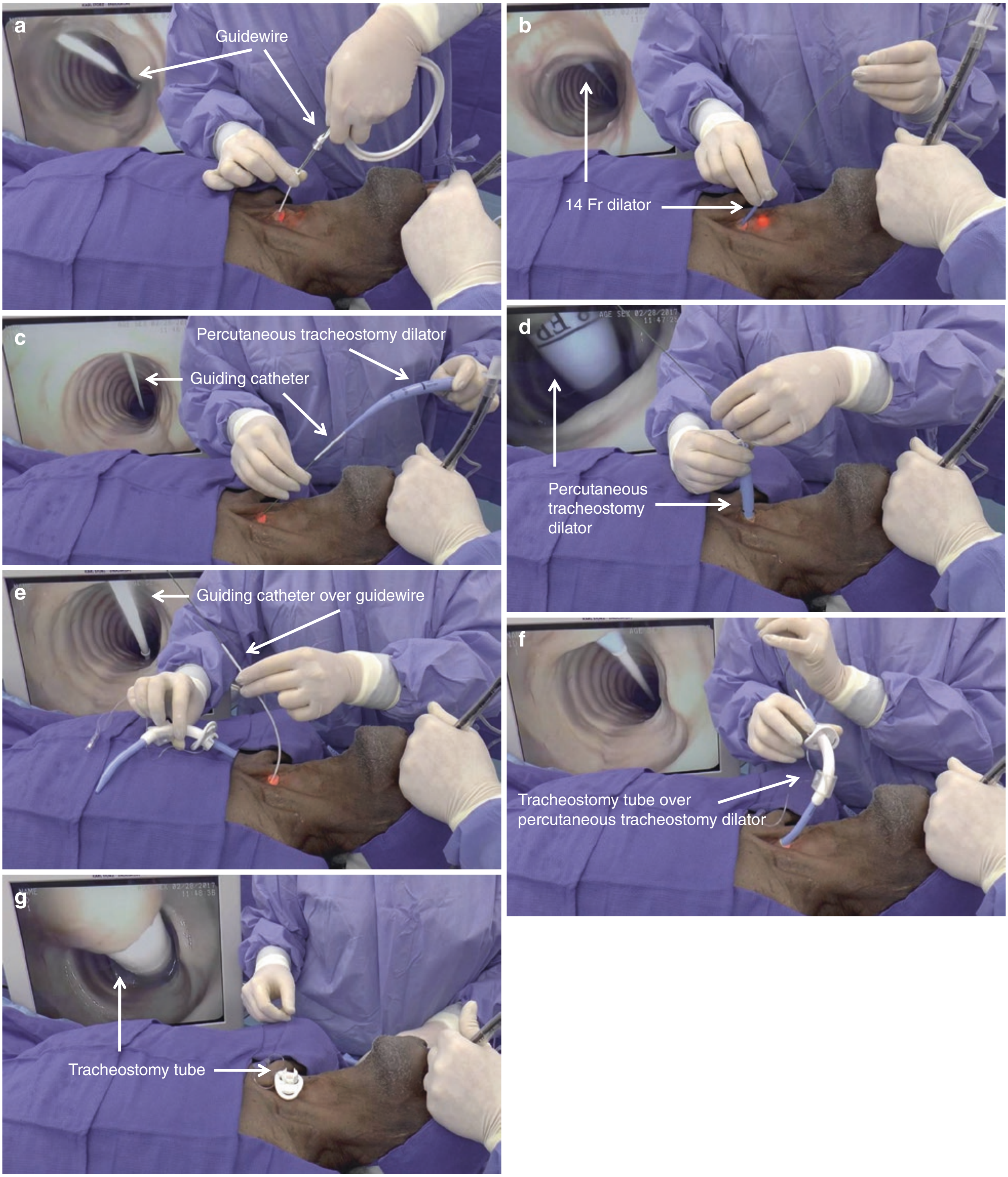
a
Guidewire
b
14 Fr dilator
c
Percutaneous tracheostomy dilator
Guiding catheter
d
Percutaneous tracheostomy dilator
e
Guiding catheter over guidewire
f
Tracheostomy tube over percutaneous tracheostomy dilator
g
Tracheostomy tube

Fig. 2.5 (**a**–**g**) Under direct vision with the bronchoscope, remove the syringe and needle, leaving the catheter in place in the airway. Feed the guidewire into the airway through the catheter (**a**). Ensure bronchoscopically that the wire passes towards the carina and not upwards to the larynx. Once the wire is in the trachea, remove the catheter. Next, use the serial dilators in the kit to widen the opening into the trachea. The 4.5 cm-long 14 Fr dilator should first be advanced into the airway over the wire, and visualized within the lumen of the trachea bronchoscopically (**b**). After this, use the single size percutaneous tracheostomy dilator with the guiding catheter positioned within it to dilate the opening further (**c**). Use the image through the bronchoscope to do this under direct visualization throughout to ensure the posterior tracheal wall is not damaged (**d**). Remove the dilator but leave the guiding catheter over the wire, positioned in the airway (**e**). Insert the tracheostomy tube, preloaded over the appropriately sized tracheostomy loading dilator, over the guiding catheter and wire into the airway (**f**–**g**). Visualize the insertion with the bronchoscope. Remove the wire, guiding catheter, and tracheostomy loading dilator. Inflate the cuff of the tracheostomy tube and suction out any secretions from the airway. Commence ventilation through the tracheostomy and remove the endotracheal tube. Finally, suture the tracheostomy to the skin in four quadrants using 0 prolene suture (see Chapter 3, Open Tracheostomy)